Novel Concept for Detection of a Fluid Flow Fault in a Pumped Fluid Heat Rejection System

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Question:

Is there a Heat Rejection System Flow Fault Detection System in The Clipper Mission?

Answer:

Yes it does have a novel concept, and that's why you are here to listen to my talk☺

Outline of Presentation

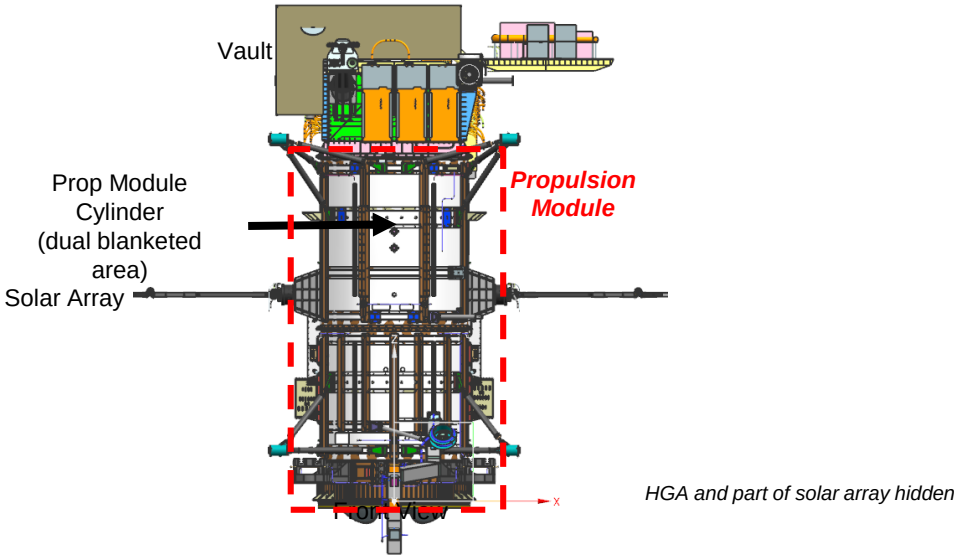
- Overview of Clipper Mission & Spacecraft
- Heat Rejection System (HRS)
- Flow Fault in HRS and its Implications
- Fault Detection Concepts Studied
- Novel Flow Fault System Designed for Clipper
- Summary
- Key Conclusions

Motivation

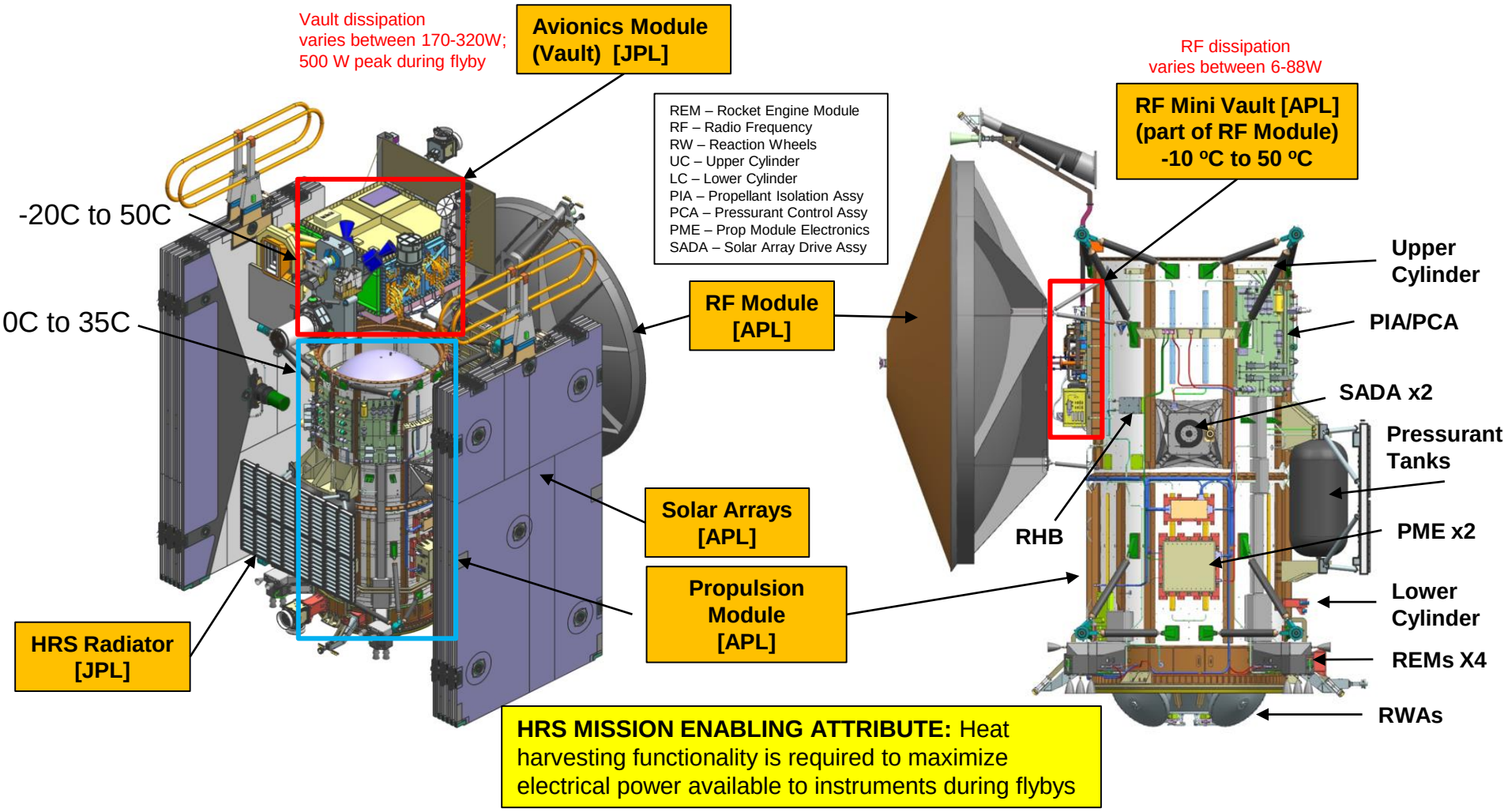
- A HRS flow fault, however improbable, can result in severe limitations or a mission failure of Europa Clipper
- Implications include rapid violations of temperature limits of components controlled by the HRS
- Hence the need for a fault detection scheme to catch the fault much sooner than its implications are realized
  - To allow for mitigation measures to be exercised

Europa Clipper Background

- **The Europa Clipper spacecraft features a large propulsion module with a cylinder that is maintained between 0 and +35 °C**
- **Deep Space Planetary Mission to Launch in 2023 to Europa, a moon of Jupiter**
- **Vast majority of its heat loss is via MLI blankets**

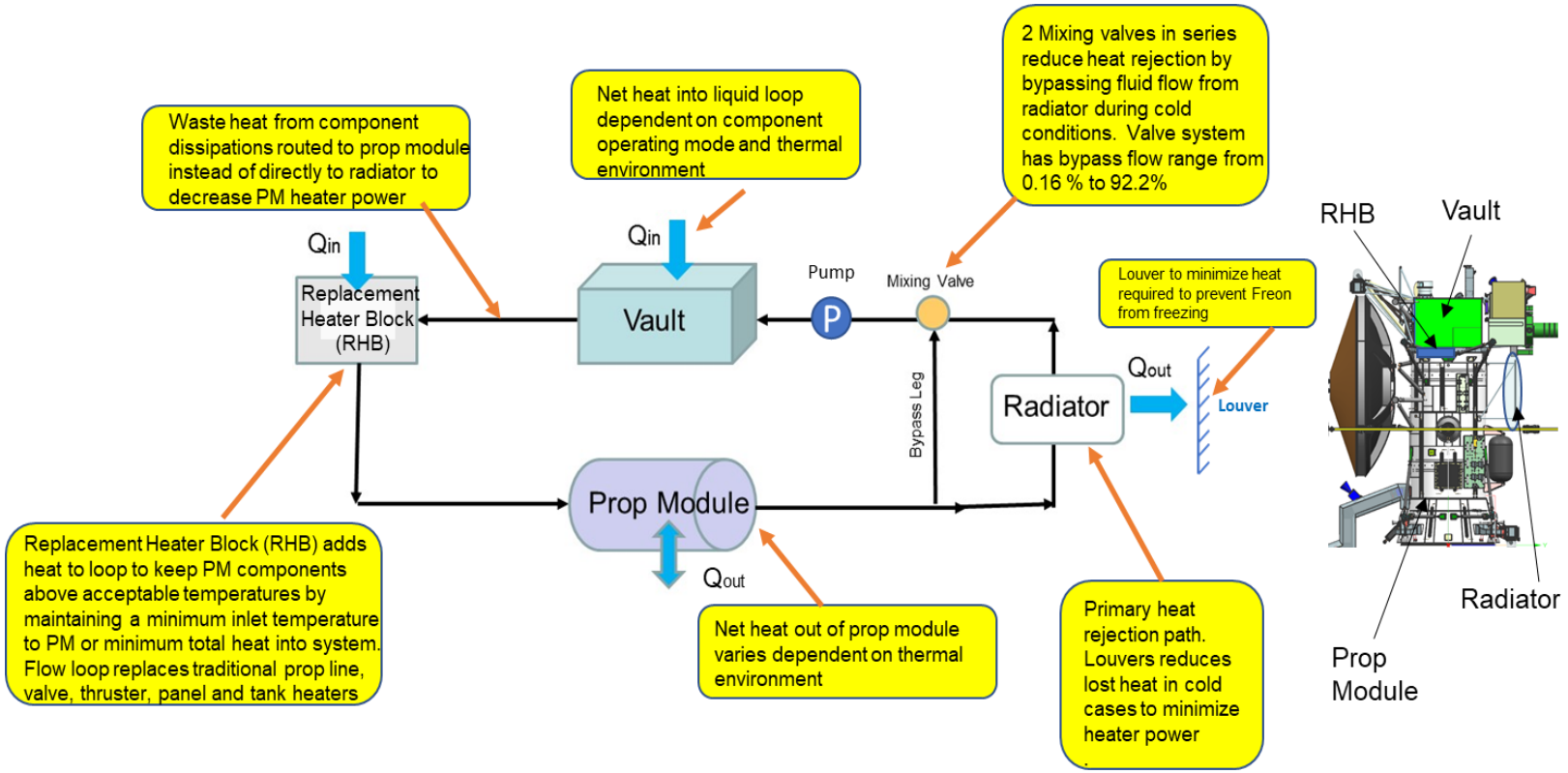


Europa Clipper



HRS MISSION ENABLING ATTRIBUTE: Heat harvesting functionality is required to maximize electrical power available to instruments during flybys

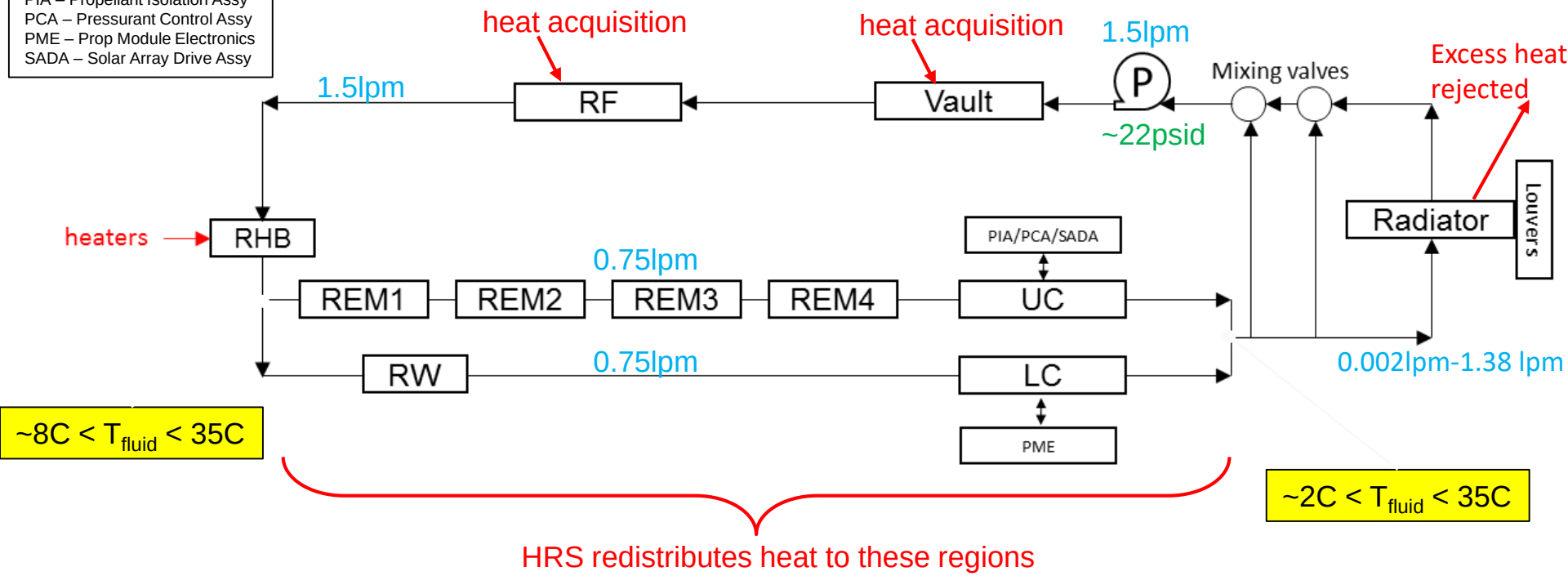
Clipper HRS Functions



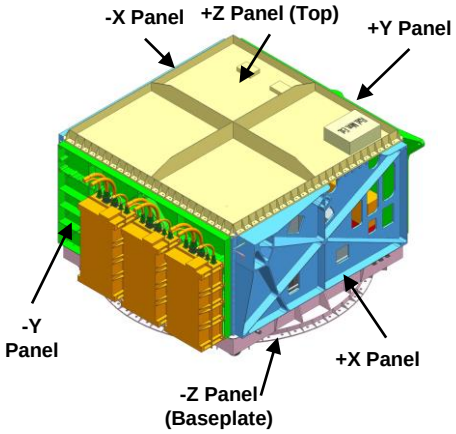
HRS is designed to use component dissipations to warm up propulsion module

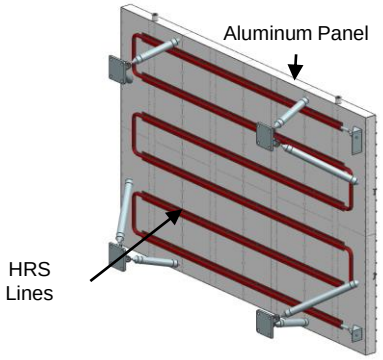
Simplified Clipper HRS Schematic

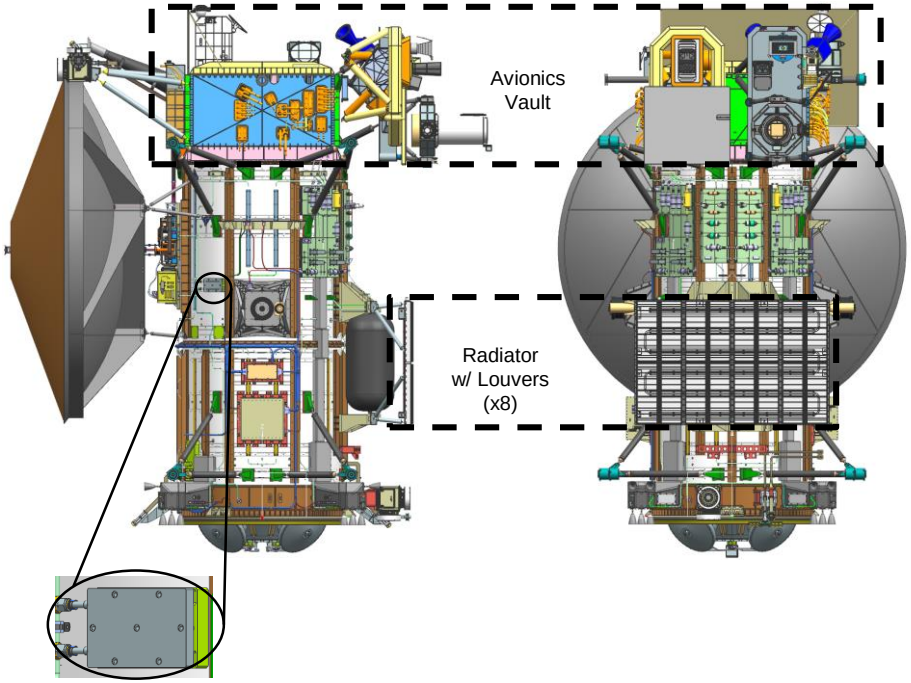
REM – Rocket Engine Module
RF – Radio Frequency
RW – Reaction Wheels
UC – Upper Cylinder
LC – Lower Cylinder
PIA – Propellant Isolation Assy
PCA – Pressurant Control Assy
PME – Prop Module Electronics
SADA – Solar Array Drive Assy

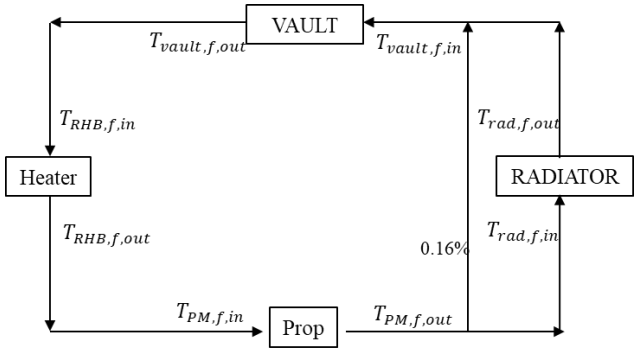


Europa Clipper HRS









Implications of HRS Flow Fault & It's Mitigation

- **If the pump were to stop working for any reason, the functionality of this loop's thermal control would be lost**
  - Causing a potentially mission jeopardizing situation because the temperatures of the controlled components could violate their allowable limits
- **Due to the importance of the thermal health of the spacecraft, the pumped loop utilizes two pumps, one primary & the other redundant**
  - With only one on at any time to conserve redundancy, lifetime and power
- **To enable this redundancy to function correctly, one needs to detect this fault before the ramifications of it are realized**
  - In terms of components violating their allowable temperature limits
- **If detected early, backup pump would be automatically energized by flight software**
  - And information about its state change transmitted to mission operators on Earth

Key Metrics HRS Flow Fault Detection

- **Minimal impact on FS resources**
  - Power, mass, size, location, software, avionics, cost & schedule
- **Autonomous, needing no oversight from ground control**
- **Allow for long blackouts of communication between spacecraft and ground control**
  - Could be as long as days in a 10 year long cruise
- **Fast response (minutes)**
  - Detect root cause before deleterious ramifications on controlled components are realized
  - Detect cause before negative impact happens
- **Simplicity in implementation**
- **Very robust and reliable**
  - Should itself be fault tolerant
- **Provide information to flight software to react to flow fault**
- **Turn on backup pump & call Earth**
- **Minimal interaction (or none) with nominal control of HRS in flight**
- **Differentiate between fault protection & nominal operation scenarios**
- **Should work in both hot/cold conditions**

Fault Detection Concepts Studied (I)

- **Pump Current Telemetry**
  - Utilizes pre-existing flight hardware
  - But does not differentiate between pump's internal faults from power being supplied to pump
  - Current measurement accuracy comparable to pump power draw
    - Measurement accuracy 0.5 A
    - Pump current draw 1 A

- **Employ a Flow Meter**
  - Does Identifies primary root cause – loss of flow
  - But flowmeters require large mass of ionization radiation shielding

- **Attach a Tachometer to the Pump Body**
  - Poor resolution & lack of development units
  - Does not differentiate output from flow stoppage fault

Fault Detection Concepts Studied (II)

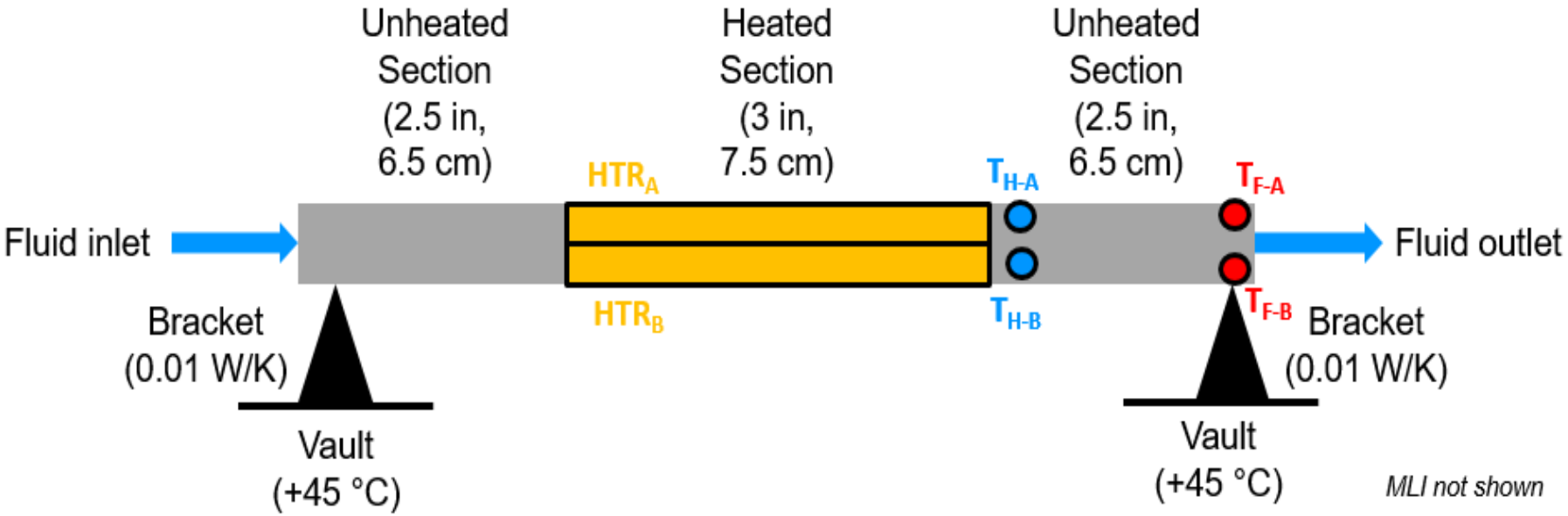
- **Detect Temp change in the RHB metal casing**
  - Power supplied to RHB would raise its temp. if flow stops
    - But fast increase in measurable temp rise would not work for small inserted powers
  - Also, RHB heated only in cold conditions, so not useful in hot conditions

- **Detect Temp change in the HRS Radiator due to Flow Stoppage**
  - Only applicable in hot conditions when fluid flows through radiator
  - Could supplant RHB temp change concept (hot vs. cold)
  - But radiator's large time constant leads to slow thermal response

- ***Baselined Concept Utilizing a Heated Section of HRS Tubing as a Watchdog for Flow Stoppage Detection***

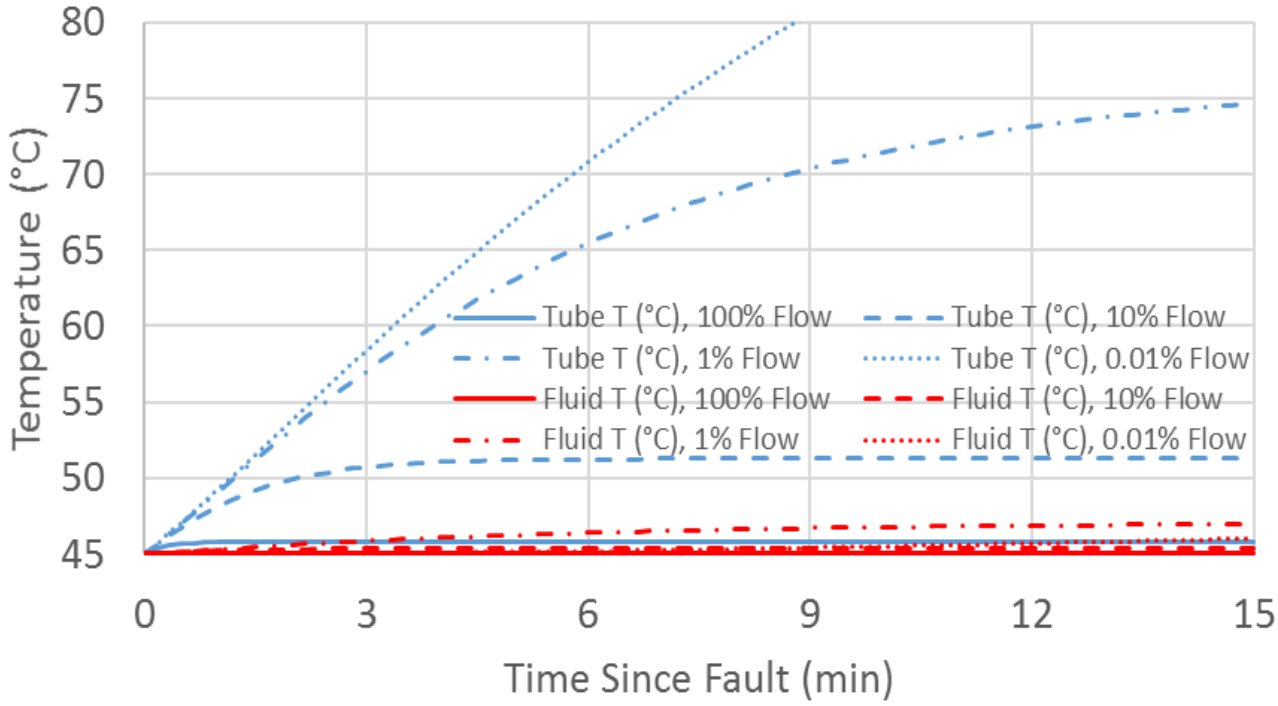
Fault Detection Scheme Utilized

- *Heated Tube Section*



HRS Flow Fault Response

- *Heated Tube Section*



- **In spite of very small heat insertion, small thermal mass of tubing responds very rapidly to this heat when the fluid flow stops**
- **E.g., even with only a 1 W heater power, tube rises by 25°C in 6 minutes when the flow stops – small heat capacity of tube (no fluid flow capacity)**
- **On the other hand, tube temperature remains almost identical to the fluid temperature when full fluid flow is maintained - large heat capacity of fluid**

Applicability to Other Missions

- **It is applicable to other missions utilizing a pumped fluid loop (single or two phase) to detect a fluid flow fault**
  - Even though this heated tube section thermal watchdog concept was conceived for the Europa Clipper HRS

- **It has several positive attributes:**
  - Provides very rapid detection of the root cause of the fault (flow stoppage)
    - Much earlier than the ramifications of the root cause fault are realized
      - Temperature limit violations of HRS controlled hardware
  - Simplicity
  - Requires minimal power, mass and volume
  - Very easy to implement
    - Film heater bonded to tube section and a PRT temperature sensor
  - Easy to monitor by flight software
  - Works in all thermal and operational conditions with no exception

Summary & Conclusions

- **A flow stoppage fault in a pumped fluid loop heat rejection system (HRS) would pose a serious risk for the thermal health of the hardware served by the HRS**
- **Very early detection of the fault is necessary to ensure that a rapid remedy in the form of turning on the back up pump is invoked**
- **Several schemes were investigated and traded off for the Europa Clipper HRS**
- **The most attractive option was baselined for fault detection & it consists of utilizing a small film heater on a section of the HRS tubing**
- **This watchdog utilizes a low power heater attached to that section of the line**
- **Once energized, it provides rapid, accurate and highly discriminatory detection of a fluid flow stoppage**
  - Indicated by a rapid rise in temperature of the heated section when the flow stops
- **Its simplicity, accuracy, speed, robustness, and ease of implementation make it very attractive for use in other missions that utilize pump fluid loops for thermal control**

Acknowledgements

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Questions & Answers?